Body-specific representations of action word meanings in right and left handers

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Abstract

If understanding action words involves mentally simulating our own actions, then the neurocognitive representation of word meanings must differ for people with different kinds of bodies, who perform actions in systematically different ways. In a test of the *Body-Specificity Hypothesis*, right- and left-handers were compared on two motor-meaning congruity tasks. Double dissociations in both action execution and recognition memory results showed that right and left handers form body-specific representations of words for manual actions.

A human mirror neuron system, responsible in part for both the perception and performance of actions, has been posited to subserve the meanings of action words[1-7]. Processing words for actions performed with the legs (e.g., *kick*) or the hands (e.g., *pick*) modulates motor-evoked potentials recorded from associated effector muscles[3] and produces somatotopically organized activation in sensorimotor cortices[1,5,7]. Mirror neurons appear to be distributed bilaterally; viewing a right or left hand in action tends to elicit activity in motor areas contralateral to that hand[8]. Yet across studies, activity in sensorimotor cortex associated with words for manual actions has been consistently lateralized to the left hemisphere[1,5-7]. This lateralization could be due to the general left-hemisphere dominance for language[9], or alternatively, it could be a consequence of testing only right-handed participants. To the extent that stimuli in previous studies[1,5-7] named actions typically performed with the dominant hand (i.e., the right hand), the observed left-lateralized motor activity supports the following claim: understanding manual action words involves mentally simulating actions, using mirror neurons contralateral to the hand that usually executes them. This mental simulation claim would be seriously challenged if the meanings of manual action words were found to be lateralized to left-hemisphere motor areas in left handers as well as right handers. By contrast, the simulation claim would be strongly supported if the components of action word meanings subserved by motor areas were found to be lateralized differently in right vs. left handers, despite the fact that language function, overall, is left-lateralized in the majority of both right and left handers[9].

The present study used the processing of manual action words in right and left handers as a testbed for the *Body-Specificity Hypothesis*: if concepts and word meanings are constituted, in part, by mental simulations of our own perceptions and actions, then their neurocognitive representations should differ for people with different kinds of bodies, who perceive and act upon the environment in systematically different ways.

Sixteen right handers and sixteen left handers, as measured by the Edinburgh handedness inventory[10], performed a 'motor-meaning congruity' task followed by a surprise recognition memory test. 96 single words appeared in the center of a computer screen, one at a time for 2 seconds each. Half were verbs naming manual actions (e.g., *paint*, *chop*, *draw*) that raters indicated they typically perform with their dominant hands, and the other half were verbs naming non-manual actions (e.g., *sigh*, *peek*, *giggle*) matched for length, frequency, and number of phonemes (see Supplementary Figure 1 and Tables 1-2). Half of the words appeared in red letters and the other half in blue letters. A red box was placed on the left of the screen and a blue box on the right (or vice versa), and a white box filled with hundreds of clear glass marbles was placed above the screen, in the middle. Participants were instructed that as soon as each word appeared they should move one marble into the box that matched the color of the letters: word meanings were task-irrelevant. For one block of 48 words participants used their left hand, and for the other block their right hand. Each block contained equal numbers of red and blue words and equal numbers of manual and non-manual action words, randomly intermixed. The assignment of colors to words, the positions of the red and blue boxes, and the sequence of the left and right hand blocks were counterbalanced across subjects. After completing the marble moving task, participants performed an old/new recognition memory test in which all of the words presented previously in red or blue were shown again in black letters, randomly intermixed with an equal number of matched new words.

Participants were not instructed to evaluate the words they saw, or even to read them, but it was expected that they would read and understand the words incidentally. If meanings of action words are constituted, in part, by mental simulation of perceptuo-motor experiences, then: (a) there should be effects of congruity between manual motor actions and the meanings of manual action verbs (but not non-manual action verbs), and

(b) right and left handed participants should show opposite effects of using their right and left hands to move marbles during incidental encoding of manual action verbs.

Right handers were dramatically faster to initiate marble movements to the correctly colored boxes when using their right hands, and left handers when using their left hands, but only when incidentally reading manual action verbs (fig 1a-b; see Supplementary Methods and Results). 2-way mixed ANOVA showed a significant interaction of Handedness (left-handed participant, right-handed participant) and Response Hand (left hand, right hand), with no main effects ($F1(1,30)=320.12$, $p=.0001$; $F2(1,94)=310.38$, $p=.0001$). By contrast, no effects of handedness or response hand were found for non-manual action verbs ($F1(1,30)<1$; $F2(1,94)<1$). The 3-way interaction of Handedness, Response Hand, and Verb Type (manual, non-manual) confirmed that the advantage of using the dominant hand to move marbles was found selectively during manual action verbs ($F1(1,30)=320.63$, $p=.0001$; $F2(1,94)=306.01$, $p=.0001$).

The magnitude of the response time congruity effect depended on participants' degree of handedness. The absolute value of participants' laterality quotients[10] correlated reliably with their response time advantage (RT non-dominant hand – RT dominant hand) for manual action words ($r^2=.36$, $t(30)=4.11$, $p=.0002$), but not for non-manual action words ($r^2=.07$, $t(30)=1.48$, *ns*).

Right handers were also much more likely to correctly recognize manual action verbs that appeared while they were using their right hands, and left handers while they were using their left hands ($F1(1,30)=35.42$, $p=.0001$; $F2(1,94)=52.92$, $p=.0001$), but no interaction of handedness and response hand was found for non-manual action verbs ($F1(1,30)<1$; $F2(1,94)<1$; fig 2a-b). The 3-way interaction of Handedness, Response Hand, and Verb Type confirmed that the advantage for recognizing words incidentally

encoded while using the dominant hand was found selectively for manual action verbs ($F1(1,30)=27.74$, $p=.0001$; $F2(1,94)=76.52$, $p=.0001$).

These double dissociations (fig. 1a, 2a), one in action execution and the other in recognition memory, provide initial evidence for the Body-Specificity Hypothesis. Right and left handers, who perform actions differently with their hands, also instantiate the meanings of manual action words differently in the brain and mind.

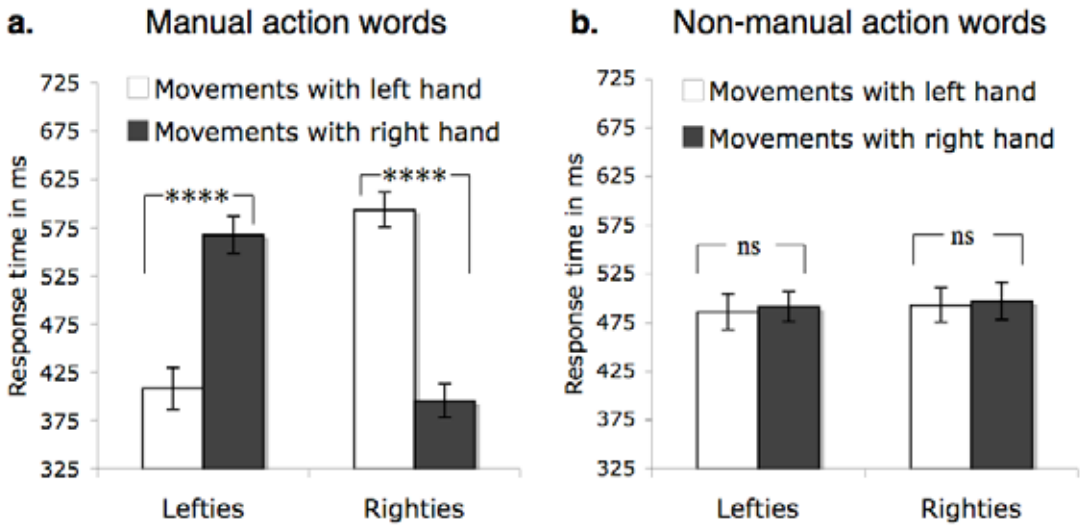

Figure 1. Mean response times in ms (± s.e.m.) to initiate marble movements for manual action words (1a, left) and non-manual action words (1b, right). ****indicates p<.0001, *ns* indicates p>.05, 2-tailed.

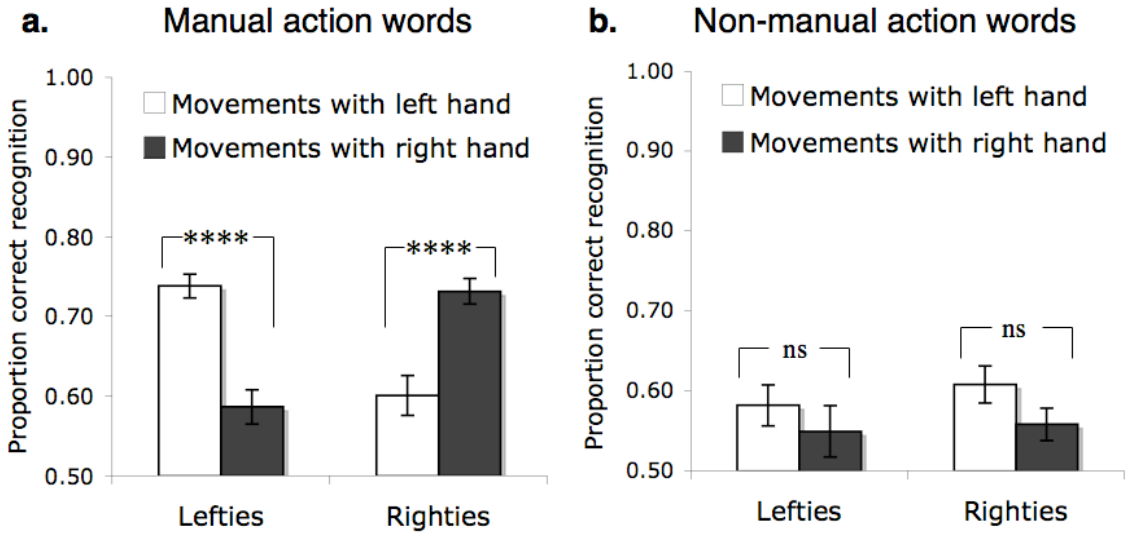

Figure 2. Proportion correct recognition (± s.e.m.) for incidentally encoded manual action words (2a, left) and non-manual action words (2b, right). **** indicates p<.0001, *ns* indicates p>.05, 2-tailed.

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